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TEST PROGRAM TO EVALUATE HUMAN RESPONSE TO PROLONGED MOTIONLESS SUSPENSION IN THREE TYPES OF FALL PROTECTION HARNESSES

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AAMRL-TR-87-055

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

HENNING E. VON GIERKE, Dr Ing
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
An experiment was conducted using 13 volunteers to evaluate the relative capabilities of three types of fall protection harnesses to provide occupant body support and restraint during post-fall suspension. A series of 39 randomized tests were conducted to evaluate the physiological effects and subjective responses to prolonged, motionless suspension in a body belt, a chest harness, and a full-body harness. Measured physiological parameters included blood pressure, heart rate, and respiratory rate. Subjects were passively suspended in each of the three harness types until subjective tolerance was reached or until symptoms developed which prompted a medical decision to terminate the test. Statistical analysis of the test durations was conducted using the Wilcoxon paired-replicate rank test. Subjective symptoms which prompted test termination were analyzed for the relative occurrence frequency in each harness configuration. Based upon suspension duration and subjective response data, the full-body harness was found to provide better occupant support and restraint for longer periods of prolonged, motionless suspension. The mean suspension time of an individual in a full-body harness was 14.38 minutes with symptoms of light-headedness and nausea prevailing as the primary

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reasons for test termination. Suspensions conducted in a chest harness lasted an average of 6.08 minutes; light-headedness and strap pressure at the axilla were the most frequent symptoms which terminated a test. Body belt suspensions lasted an average of 1.63 minutes; difficulty breathing along with strap pressure to the abdominal area accounted for the most frequent symptoms prompting test termination.

PREFACE

This research was accomplished by the Biomechanical Protection Branch, Biodynamics and Bioengineering Division of the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL). The effort was accomplished under Project 7231, Task 723120 and was partially sponsored by the Occupational Health and Safety Administration of the United States Department of Labor. This report describes the research objectives of the test program and the methods used to accomplish the experiments, presents and analyzes the collected data, summarizes the results of the evaluation, and provides recommendations.

The authors wish to express their gratitude to the Branch personnel who participated in the planning, preparation, and implementation of these experiments and those who assisted in the preparation of this technical report. Special recognition is given to Sgt Mark P. McDaniel for scheduling and preparing the subjects prior to each test; SSgt Daniel J. Beachy for serving as safety monitor and equipment operator, and Mrs. Jeni Blake for her administrative support in the preparation of this documentation.

Photographic support was provided by the Technical Photographic Division of the 4950th Test Wing. Special thanks are offered to the many personnel who provided the photographic services.

Instrumentation support was provided by the Scientific Services Division of the Dynalectron Corporation under Air Force contract F33615-83-C-0500. Mr. Harold F. Boedeker was the engineering supervisor for the Dynalectron Corporation.

Anthropomorphic measurements of the test subjects were collected by Dr. Kenneth W. Kennedy of the Workload and Ergonomics Branch, Human Engineering Division of AAMRL and Mr. Greg Zehner of Anthropology Research Project Incorporated. The assistance of these individuals is gratefully acknowledged.

The authors also express their gratitude to DB Industries, Inc. and the Research and Trading Corporation for supplying the harnesses used in this research effort.

Special commendation is given to the USAF officers and enlisted personnel who volunteered to participate in these suspension experiments. The success of this investigation was due to the continuing interest and enthusiastic support of these volunteers and to the devotion and professionalism of the entire team of government and contractor personnel.

Lt Colonel John F. Seaworth is Chief of Cardiopulmonary Services at the Wright-Patterson AFB Medical Center.

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SECTION 1
INTRODUCTION

The adequacy of current fall protection harnesses and the occupant's physiological response to suspension is of vital interest to occupational safety since workers may be suspended in harnesses for a period of time awaiting rescue. The Department of Defense requirement for high-altitude parachute-descent missions may require the personnel to be suspended in a harness for 30 minutes or more (Allman et al. 1985). Unfortunately, the research that has been done in the area of fall protection and prolonged human suspension is limited. Therefore, there is a limited basis for equipment design decision or equipment standardization.

A. BACKGROUND

Dr. Maurice Amphoux (1982a, 1982b) studied five subjects between the ages of 18 and 59 years during passive suspension. The harness configurations evaluated were a torso harness, a parachute harness, a waist belt with shoulder straps, and a thoracic belt. The subjects were suspended from lanyard attachments. Subjects suspended in the harnesses that supported the whole torso were able to tolerate prolonged suspension for longer durations compared to the waist belt suspension system. The longest suspension time for the torso harnesses was 43.25 minutes. The parachute harness was tolerated for a maximum of 28.17 minutes. Two subjects who were suspended using the waist belt with shoulder straps tolerated suspension for 1 minute and 3 minutes. Subjects suspended using a thoracic belt tolerated suspension for approximately 1 minute. Therefore, Dr. Amphoux concluded that suspension tolerance was affected by the specific harness or restraint system and that maximum suspension tolerance occurred with the torso harnesses. In addition, Dr. Amphoux did not leave any doubt that ventral and thoracic belts were to be prohibited and that the problems associated with prolonged suspension after the fall could be as acute as those associated with the arrest of the fall. The medically adverse effects that were encountered included lower extremity numbness, respiratory distress, nausea, dizziness, a variety of dysrhythmias, and abdominal, shoulder, or groin pain. The dysrhythmias included tachycardia, bradycardia, and premature ventricular contractions. However, these tests did not clearly define the pathophysiological mechanism responsible for the adverse effects. Dr. Amphoux suggested that the mechanism may have a respiratory, cardiac, and circulatory basis.

In 1968 our Laboratory conducted tests in which five volunteer subjects were suspended in a PCU-3/P integrated parachute and torso restraint harness for approximately 30 minutes (Baumann, 1968). Four of the five subjects tolerated a 30-minute static suspension with only minor discomfort. The anatomical areas which were in contact with the harness leg straps were red and slightly painful. Three of the subjects noticed marked discomfort of the lower legs and feet associated with numbness during the exposures. This discomfort subsided spontaneously with repositioning of the buttocks and leg straps. All the symptoms of the subjects resolved within 24 hours. One subject lost consciousness at 27.75 minutes after the start of the test. He was lowered,

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treated, and regained consciousness at 28.50 minutes. He remained in a semi-conscious state for 3 to 5 minutes before becoming fully alert. His loss of consciousness was attributed to venous pooling caused by forward body positioning and an inadequate pre-test diet.

In a personal communication with Dean Smith (10 January 1985), President of Capitol Safety Associates, he described a human suspension test that they had conducted to compare the body belt to the full-body harness. The volunteer was suspended face down in a three-inch body belt. The maximum tolerable suspension time was 60 seconds. However, when the volunteer was suspended in a body harness similar to a USAF parachute harness, the subject was able to tolerate suspension for 5 minutes. The experiment was discontinued after five minutes as routine, and not because of any symptoms the subject had developed. The subject indicated that he could have tolerated a much longer suspension.

In 1978 Geneva Spurr Limited Incorporated tested seven different mountaineering harnesses with ten subjects (Nelson, 1972). These harnesses varied from a bowline on a coil, which is just a rope around the waist, to a troll body harness which incorporates straps around the waist, thighs, and upper chest, and a REI sit harness which consists of a seating pad with waist and thigh straps. The average suspension durations recorded for these represented harness types were 0.40 minutes, 7.50 minutes, and 17.35 minutes, respectively. Some of the symptoms experienced during these tests included lower- and upper-body numbness, intense pain, respiratory distress, uncontrolled shaking, loss of consciousness, a very weak pulse, and an almost universal narrowing of pulse pressure. From their test data, which appeared in a mountaineering magazine, the researchers concluded that vertical suspension can cause loss of consciousness without prior trauma or blood loss, and that an unconscious climber who remains in the vertical position is in danger of brain damage and eventual death within 4 to 6 minutes of fainting.

In 1985, Dr. Norbet Schauer and Christian Damisch of the University of Sports Science in Innsbrook, in Association with the Austrian Mountain Association conducted a study of mountaineering harnesses and their relative safety (Damisch, 1985). Their test program used 16 test subjects in 46 suspension tests involving a variety of harness types. The harnesses generally consisted of thigh, waist, and lower-chest belts with a cross set of shoulder straps having a ventral attachment point. Subjective responses, blood pressures, and heart rate were monitored during the 10-minute motionless suspension. Symptoms that were experienced included diaphoresis, pallor, a decrease in measurable blood pressure, an increase in heart rate, dizziness, intense strap pressures, and numbness in both arms and legs. Their conclusions were that a motionless subject in a chest/seat strap harness combination is subject to orthostasis with pooling of the blood in the lower extremities, subsequent irreversible protracted shock, and mountain climber's "Rescue Death". The phenomenon known as "Rescue Death" is believed to be a result of an acute overload of the right ventricle resulting in right ventricular failure. This overload is due to a sudden return of blood from the lower extremities, where it had pooled, back to the heart. Another phenomenon noted during these tests was that as the time of suspension increased, the subjects felt less and less strap pressures. The researchers believed that the decrease in pain was probably due

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to a cessation of conducted neural impulses from the nerves in the superficial skin areas due to overpressure. This idea, they claimed, is supported by the pain and tingling sensations which occur after pressure on these areas is released.

Dr. Bernard Hearon and James Brinkley concluded from their review of the literature on fall arrest and post-fall suspension (1984) that the pathophysiological mechanism involved in post-fall suspension had not yet been defined experimentally. The mechanism that they suggested is that venous pooling occurs in the lower extremities during motionless, prolonged suspension which contributes to a decreased cardiac output and venous return to the heart. The decreased cardiac output may explain the symptoms of light-headedness and hypotension observed in previous experiments. Pathophysiological consequences attributed to venous pooling in the lower extremities include decreased right atrial pressure, decreased venous return to the heart, and a decrease in the cardiac stroke volume.

B. PROGRAM OBJECTIVES

The knowledge and data acquired from this study are intended to be used to provide design and evaluation criteria for fall protection equipment and airborne personnel delivery systems. The US Department of Labor, Occupational Safety and Health Administration (OSHA) is currently developing new regulations governing the design of fall protection equipment. A draft regulation that has been proposed by OSHA has been challenged due to the inadequacy of existing supporting evidence. The International Standards Organization is also reviewing a draft standard for fall protection equipment; however, the US Delegation is currently withholding approval since the provisions of the standard are supported only by the limited research of French investigators. Therefore, OSHA encouraged this Laboratory to conduct this research.

The primary objective of this research effort was to evaluate the relative capabilities of three types of fall protection harnesses to provide occupant body support and restraint during post-fall suspension. The three configurations evaluated were a body belt, a chest harness, and a full-body harness. The second objective of this research effort was to assess the hemodynamic and cardiovascular effects of prolonged, motionless suspension in the various body harnesses and body belts.

This report describes 1) the experimental design; 2) the test equipment, methods, and facilities; 3) the test results and analysis; and 4) provides a discussion of the results.

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SECTION 2
TECHNICAL APPROACH

A. EXPERIMENTAL DESIGN

The null hypothesis evaluated in this test program was that there are no statistically significant differences in the subjective and the physiological responses recorded during suspensions of volunteers in three harness types.

For all the tests in this series subjects were instructed to remain motionless during the suspension. No corrective movements or strap adjustments were permitted once the subject was suspended. This was to simulate an unconscious or injured state. The subjects were suspended until their subjective tolerance was reached or until symptoms of hypotension or syncope developed, which warranted a medical decision to terminate the test. Subjects were, however, instructed to remain suspended for as long as possible in order to better approximate a physiological limit.

Individual subjects and the order of their exposure to each of the harness types were collectively randomized. However, due to scheduling difficulties complete randomization between subjects was not possible.

Twelve males and one female subject of the AAMRL Impact Acceleration Stress Panel participated in this test program. The panel is composed of volunteer active-duty Air Force members whose primary duties do not involve participation as subjects. All subjects were qualified to participate only after successfully completing an intensive medical screening evaluation. This evaluation was directed by the panel physician and consisted of medical history screening, physical examination, visual acuity, audiometry, blood pressure, routine laboratory examinations (blood work and urinalysis), standard 12-lead electrocardiogram (EKG), pulmonary function tests, electroencephalogram, treadmill exercise stress test and x-rays, including chest, skull, and complete spine films.

Informed consent was provided by all subjects on an ongoing basis during the test program. Prior to each phase of testing, subjects received a thorough briefing on the experimental procedures and potential medical risks. The subjects signed a witnessed consent form attesting to the fact that a detailed briefing was received as well as a summary of the experiment. The medical investigator continued to stress that any subject was free to withdraw at any time for any reason.

Suspension tests were conducted in each harness using an Alderson Research Laboratories, Inc. model VIP-95 anthropomorphic dummy prior to initiating tests with volunteer subjects. The VIP-95 dummy is designed to represent a 95th percentile (weight) adult male. As an additional safety precaution, a dummy test was performed each day prior to testing with human subjects.

The controlled variables during these experiments were the harness type, the test subjects, and to a lesser extent, harness fit, which was dependent upon subject size and build.

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The observable variables which were measured during these experiments included an EKG, distal blood pressure, respiratory rate, and test durations. EKG data were analyzed by microcomputer for the determination of heart rate and dysrhthmias that might occur during a test.

Significant unobservable variables during these experiments included the amount of lower body blood pooling and central blood pressure.

B. EVALUATION CRITERIA

The physiological measurements obtained during these experiments included the EKG, blood pressure, and respiration-rate time histories, and the relative psychophysiological and subjective-response time histories.

Test durations were recorded and the means and standard deviations calculated for each harness type.

The Wilcoxon paired-replicate rank test was the statistical technique selected to compare the test durations of each harness type. A 90 percent confidence level was defined as the level of significance for rejection of the null hypothesis, assuming a two-tailed test.

SECTION 3
TEST EQUIPMENT, METHODOLOGY, AND FACILITIES

A. HARNESSES

Three types of fall protection harnesser were evaluated:

1. Body belt (Research and Trading Corporation, style no. 400). This harness consists of a four-inch wide padded belt with a friction buckle. It is worn around the waist and is adjustable. The belt has a D-ring for attachment to a suspension lanyard (Figures 1, 2, 3).

2. Chest harness (DB Industries, Inc., model no. LS1203). This harness consists of 1 3/4-inch wide waist and chest belts with shoulder straps connecting these two belts to a suspension D-ring. The D-ring is located between the shoulder blades of the occupant (Figures 4, 5, 6).

3. Full-body harness (Research and Trading Corporation, style no. 425). This harness is similar to a parachute harness and is constructed of 1 3/4-inch wide straps encircling the torso and the upper thighs. A strap, referred to as a buttock sling, connects the two thigh straps posteriorly. A D-ring is used to attached a fall-arrest lanyard and is usually located between the shoulder blades of the occupant (Figures 7, 8, 9).

Only minor differences exist among the styles of body belts and chest harnesses commercially produced. However, the differences among the styles of full-body harnesses that are commercially available are more significant. These styles differ in the strap configurations, occupant position upon suspension, and load distribution. The particular full-body harness used in the test program was chosen from several styles available from the manufacturer because its thigh-strap configuration indicated a possibility for increased pressure in the groin area which might shorten occupant suspension time. Each harness was snugly fitted to the subject, but not to the point where the range of extremity motion or torso movement was restricted. This ensured subject safety as well as mobility.

B. LANYARD EXTENDER AND HOIST MECHANISM

A six-foot long nylon lanyard manufactured by DB Industries with a non-locking snap hook at each end was used to suspend subjects. One snap hook was attached to the D-ring of the harness and the other connected to a steel cable of a hoist. A hoist was used to raise and lower the test subject.

C. TEST AREA

Prior to each test, the test area was secured and isolated from the rest of the test bay by draped partitions and rope barriers. An 8 foot by 10 foot safety mat was placed on the section of floor over which the subject would be suspended.
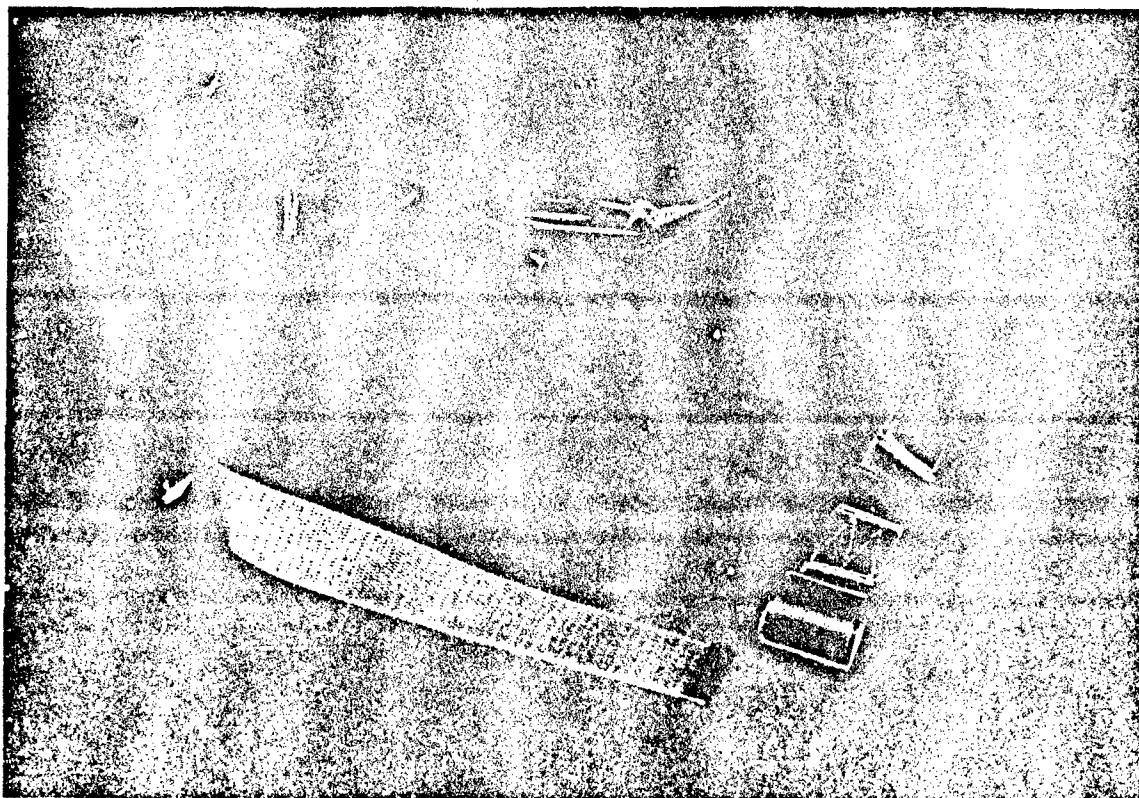
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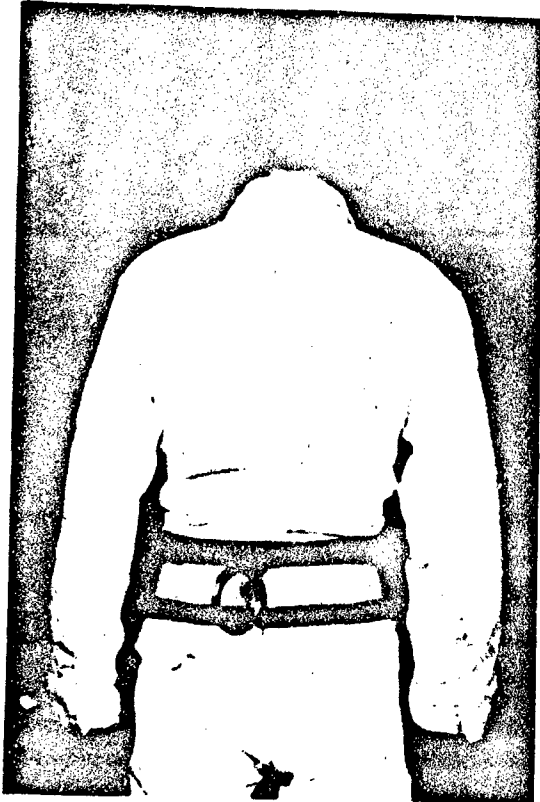FIGURE 1. BODY BELT

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FIGURE 2. POSTERIOR VIEW - BODY BELT
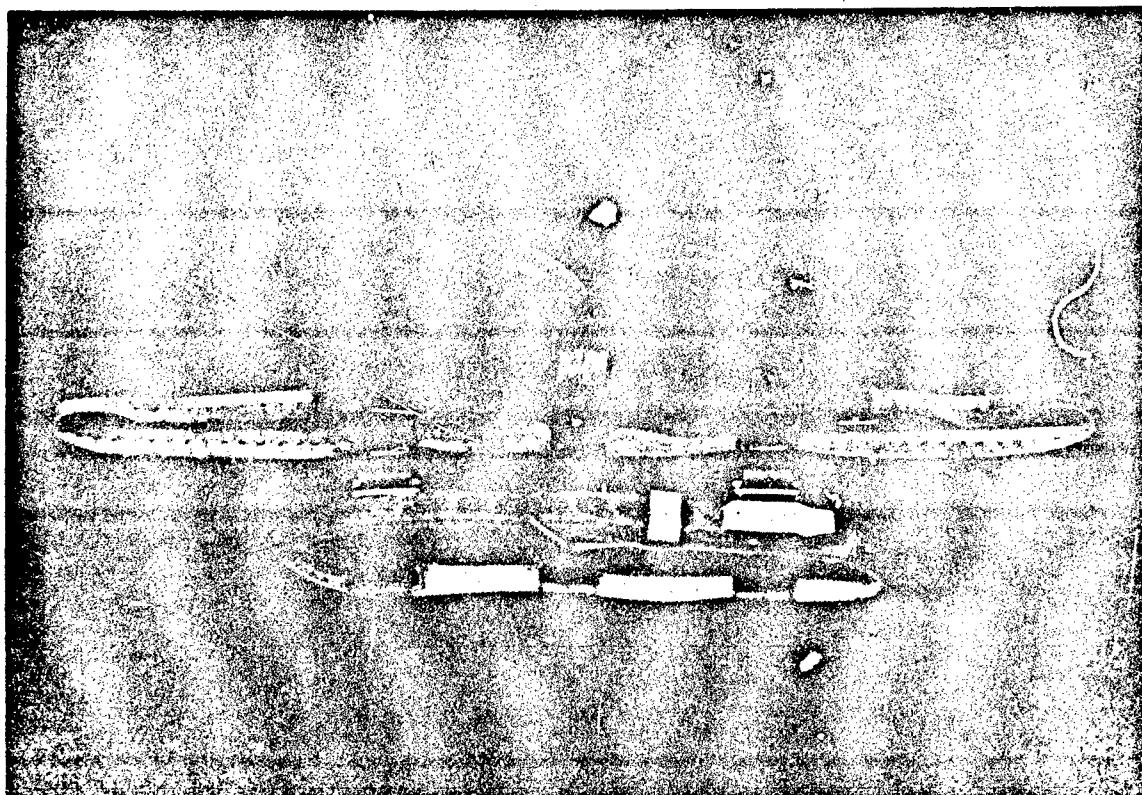
FIGURE 3. ANTERIOR VIEW - BODY BELT

FIGURE 4. CHEST HARNESS

FIGURE 5. CHEST HARNESS - ANTERIOR VIEW

FIGURE 6.
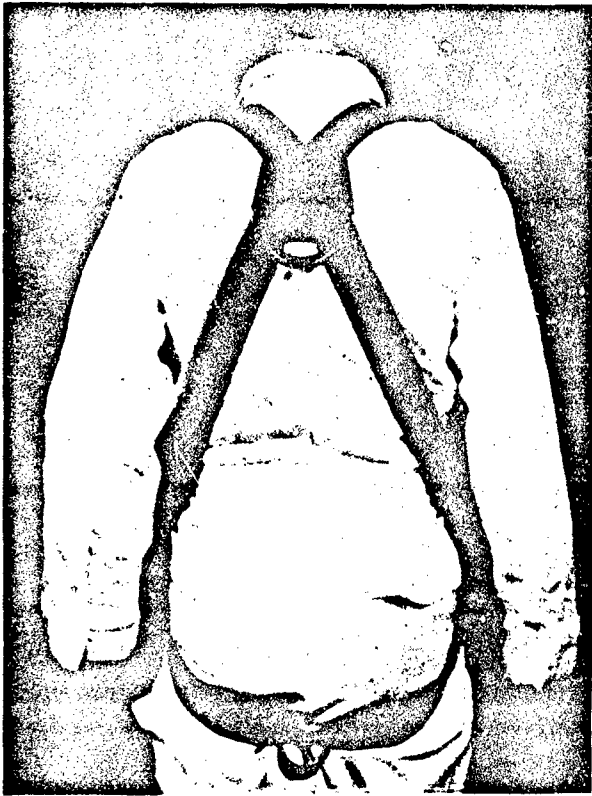CHEST HARNESS - POSTERIOR VIEW

FIGURE 7. FULL-BODY HARNESS

FIGURE 8. FULL-BODY HARNESS -
POSTERIOR VIEW

FIGURE 9. FULL-BODY HARNESS -
ANTERIOR-LATERAL VIEW

D. DATA ACQUISITION AND INSTRUMENTATION

A standard sphygmomanometer was used to measure a subject's distal blood pressure. A Holter EKG monitor and a Hewlett-Packard EKG telemetry unit were both used to monitor a subject's EKG for heart rate and waveform dysrhythmias. The EKG telemetry data were transmitted to a strip-chart recorder and were used by the medical monitor to evaluate the subject's heart rate before, during, and after the test. The Holter EKG monitor recorded data on a casette tape which were later analyzed by microcomputer and were used to provide a more comprehensive evaluation of the subject's electrocardiographic waveform.

Respiratory rate was monitored using a Yellowspring's Instrument no. 511 thermistor inserted into a nasal air cannula and connected via a balancing and amplifying bridge network to a model 260 Gould Brush Recorder. Respiratory rate was calculated from the the temperature changes caused by inspiration and expiration.

The subject's responses to a questionnaire were recorded on a casette tape using microphones worn by the test conductor and the subject. The questionnaire was administered throughout the test and was designed to determine the subject's perceived physiological and psychophysiological condition.

Measurement of the durations and event markings for EKG data was accomplished using separate synchronized electronic timers.

Photographs were taken of the subject and equipment configuration prior to suspension and during the first few minutes of suspension to document the subject's position in the harness.

E. EXPERIMENTAL SEQUENCE

The particular harness styles and subjects to be tested as dictated by the test matrix were provided to the test conductor at the beginning of each day of testing. The test conductor assured consistency of the test procedures and directed the activities of personnel in the test area in accordance with the test plan and a detailed checklist.

The first test of each day was done using an anthropomorphic dummy. The harness assembly, lanyard, and hoist mechanism were tested and visually inspected to ensure structural integrity and proper function.

Subject preparation was accomplished concurrent with the preparation of the test equipment. Prior to each suspension test, the subject provided a brief, interval medical history and was physically examined. Emphasis was placed on medications, abnormalities of recent sleep patterns or recent overindulgence in food or alcoholic beverages. No subject was suspended with symptoms which may have obscured detection of test-related symptoms or injury or which may have indicated a predisposition to such symptoms or injury.

All subjects wore white, cutoff long underwear to allow mounting of instrumentation. The female subject wore a bathing suit in addition to the

cutoff long underwear. Each subject was instructed to void prior to entering the test area.

Next, the subject's baseline values for respiratory rate was obtained. The medical monitor or medical technician obtained the subject's baseline blood pressure and recorded the baseline EKG on a strip-chart recorder. The subject then reviewed the test questionnaire with the test conductor.

Final pre-test acitivity consisted of the hookup of the lanyard to the harness D-ring, documentation of the test configuration and subject by still photographs (both a frontal and lateral view), securing of the test area by the test conductor, and a review of the test conductor's safety and equipment checklists. Subject and medical monitor verbal acknowledgements to proceed were obtained and a thirty-second countdown was initiated. The subject was then raised to approximately six inches off the laboratory floor. A photograph of the subject was then taken and the physiological, psychophysiological, and subjective conditions of the subject were immediately checked. These conditions were repeatedly checked at select intervals throughout the test.

The test was terminated when the subject reached his or her subjective tolerance or when symptoms appeared which warranted a medical decision to end the suspension. At the signal to terminate, the subject was lowered to a sitting position. After stabilization of the subject's vital signs, the subject was then placed in a supine position and the harness straps loosened. Post-suspension data were recorded at each stage of the test termination. When the subject felt fully recovered, he was assisted to a sitting position, rechecked, and then permitted to stand. The harness and test instrumentation were removed from the individual and a brief post-test physical examination was accomplished. Suspensions for each subject occurred no more frequently than once in a 72 hour period to allow time for recovery from any occult injury.

During testing, an ambulance crew was alerted and standing by within one-half mile of the test facility. In addition, emergency medical equipment was available in the test area for use by the physician monitor in the event of an emergency. This equipment included a defibrillator, oxygen equipment, intubation equipment, IV solutions and equipment, appropriate emergency drugs, a backboard, harness cutters, and bandages.

SECTION 4
RESULTS

This experiment evaluated a full-body harness, a chest harness, and a body belt during motionless prolonged suspension. Thirty-nine suspension tests were performed with 13 volunteers. Table 1 presents the mean, standard deviation, and range of the suspension duration for each of the harnesses tested. A plot of the mean duration for each harness is presented in Figure 10. Table 2 presents the symptoms which were primarily responsible for termination of a particular suspension. In a few instances multiple symptoms contributed to termination of a particular suspension. These data show that the most frequent symptom causing termination of a suspension in the full-body harness was light-headedness and nausea. Paresthesias (tingling, numbness) of the extremities and pressure to the groin area due to the thigh straps occurred with less frequency. The symptoms responsible for test termination in the body belt were primarily difficulty breathing and an unacceptable level of abdominal-strap pressure. During suspension in a chest harness, the symptoms experienced were varied but more closely paralleled those experienced in a full-body harness than the body belt. High levels of discomfort caused by strap pressure at the axilla (underarms); light-headedness; and extremity paresthesias prevailed as frequent symptoms for suspension termination.

TABLE 1
SUMMARY OF SUSPENSION DURATION DATA

	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
Total Number of Tests	13	13	13
Range of Durations (Min)	5.08 to 30.12	0.62 to 13.13	0.35 to 4.76
Mean Duration (Min)	14.38	6.08	1.63
Standard Deviation	± 8.01	+3.35	+1.25

The duration of the suspension and the primary reason for termination of the suspension for each subject for each test harness condition are presented in Table 3. Table 4 is the symptom key to accompany Table 3. The data show that the full-body harness was tolerated for a longer mean period of suspension (14.38 min) compared to the chest harness (6.08 min) and the body belt (1.63 min). The body belt was tolerated for the shortest mean duration (1.63 min). The female subject was able to tolerate the body belt for 4.77 minutes. Male subjects suspended in the body belt had an equilibrium position in which they were face down and in a horizontal or jack-knife position (Figure 11). The female subject's position in the body belt was more vertical, and this position contributed to her longer endurance in that harness compared to the other subjects (Figure 12). This equilibrium position is consistent with her relatively higher lower-body mass.

Subjects suspended in the chest harness and full-body harness are shown in Figures 13 and 14.

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TABLE 2

SYMPTOMS PRIMARILY RESPONSIBLE FOR TEST TERMINATION

SYMPTOMS	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (Percentage*)		
Difficulty Breathing	0 (0)	0 (0)	8 (62)
Strap Pressure: Axilla	0 (0)	4 (31)	0 (0)
Strap Pressure: Abdomen	0 (0)	2 (15)	7 (54)
Strap Pressure: Groin	2 (15)	0 (0)	0 (0)
Extremity Paresthesias	3 (23)	3 (23)	0 (0)
Peripheral Vision Loss	1 (8)	0 (0)	0 (0)
Drowsiness	1 (8)	1 (8)	0 (0)
Anxiety	0 (0)	1 (8)	0 (0)
Nausea	4 (31)	2 (15)	1 (8)
Head/Body Flush	3 (23)	2 (15)	2 (15)
Light-Headedness	6 (46)	5 (38)	0 (0)
Syncope	1 (8)	0 (0)	0 (0)

NOTE: Multiple symptoms may have contributed to the test termination.

*Percentage reflects the number of responses divided by the total number of tests for a given harness type.

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TABLE 3

INDIVIDUAL SUSPENSION DURATIONS AND SYMPTOMS PRIMARILY
RESPONSIBLE FOR TEST TERMINATIONS

SUBJECT ID	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
B1	18.03 minutes (I,J)	5.80 minutes (F,G,H)	0.55 minutes (G,M)
D3	5.72 minutes (A)	4.05 minutes (A,C)	1.32 minutes (M)
K2	5.08 minutes (A)	4.75 minutes (A)	1.25 minutes (M)
K3	9.50 minutes (A)	9.67 minutes (A,H)	4.77 minutes (C,M)
H8	14.23 minutes (A)	8.72 minutes (A)	0.35 minutes (G,M)
H9	17.67 minutes (H)	0.62 minutes (F)	1.60 minutes (G)
L3	19.83 minutes (E,H)	9.42 minutes (F,G)	1.67 minutes (G)
M16	5.98 minutes (C,D)	3.83 minutes (J)	1.73 minutes (G)
M18	7.00 minutes (B)	4.15 minutes (A)	1.22 minutes (B)
O2	11.08 minutes (B,E)	3.05 minutes (F,H)	0.43 minutes (G)
P5	26.28 minutes (B,H)	5.30 minutes (B)	3.67 minutes (M)
S7	16.50 minutes (A,B)	13.13 minutes (B)	1.50 minutes (C,G,M)
T4	30.12 minutes (A,C,K)	6.50 minutes (K,L)	1.17 minutes (M)

NOTE   Letters in parenthesis correspond to the primary symptoms which terminated the test. The symptoms are listed and keyed on the following table.

TABLE 4

SYMPTOM TABLE TO ACCOMPANY SUBJECT DURATION SHEET (Table 3)

A - LIGHT-HEADEDNESS

B - NAUSEA

C - HEAD FLUSH/HOT FLASH

D - SYNCOPE

E - STRAP PRESSURE: GROIN

F - STRAP PRESSURE: AXILLA

G - STRAP PRESSURE: ABDOMEN

H - LIMB TINGLING/NUMBNESS/HEAVINESS

I - PERIPHERAL VISION LOSS

J - TOTAL BODY FLUSH

K - DROWSINESS

L - ANXIETY
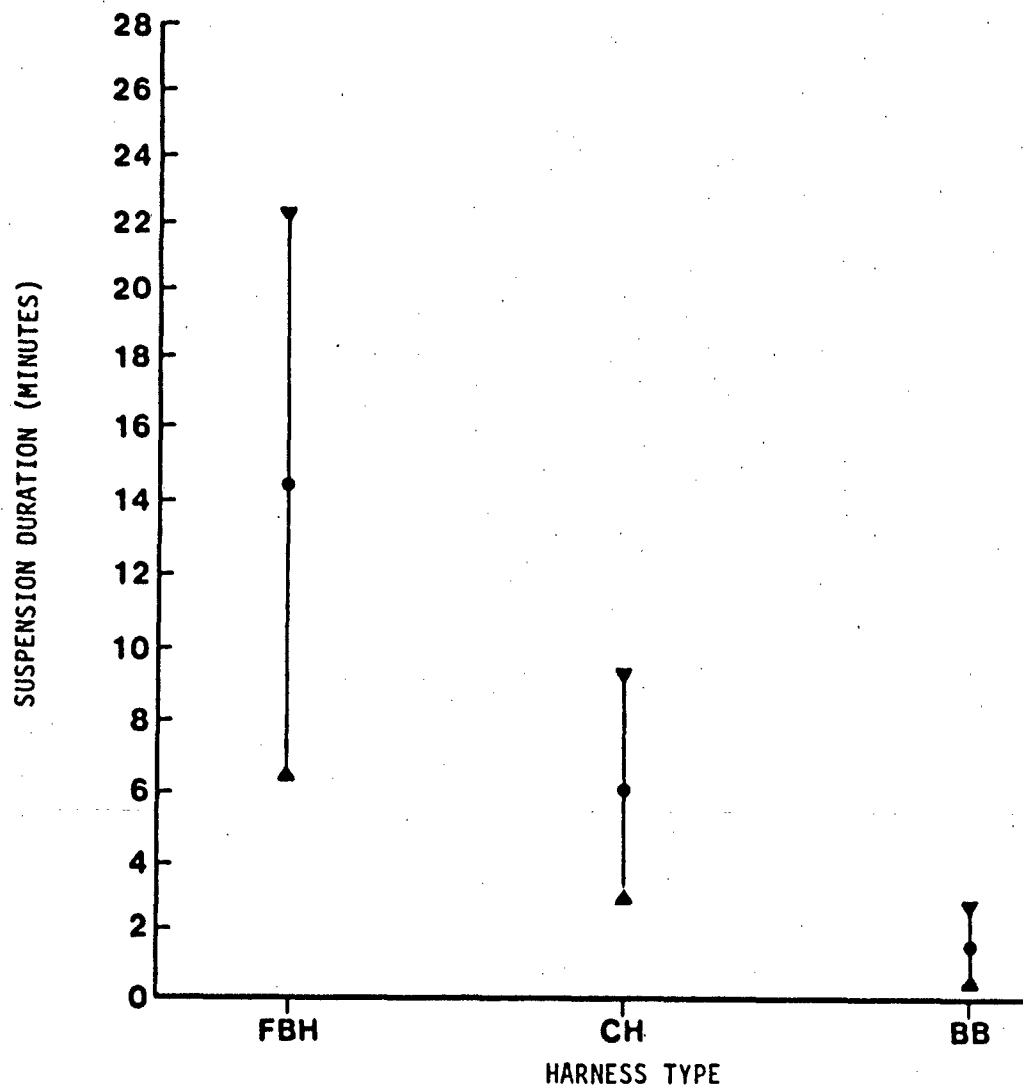
M - DIFFICULTY BREATHING

FIGURE 10. PLOT OF THE MEANS AND STANDARD DEVIATIONS OF SUSPENSION DURATION FOR EACH TYPE HARNESS

FIGURE 11.
SUSPENSION IN A BODY BELT - MALE

FIGURE 12. SUSPENSION IN A BODY BELT - FEMALE

FIGURE 13. SUSPENSION - CHEST HARNESS

FIGURE 14.
SUSPENSION - FULL-BODY HARNESS

Statistically significant differences in the suspension durations were observed. The null hypothesis that was rejected was that there were no differences in the suspension durations among the three types of harnesses evaluated.

Table 5 presents the number of times a medical decision by the physician terminated the experiment compared to the number of times the subject requested that the experiment be stopped. A medical decision was more frequently the reason for termination during suspension in the full-body harness and chest harness than the body belt. The medical decisions were based on symptons of light-headedness, nausea, head/body flush, and drowsiness. Reasons for voluntary termination included extremity paresthesias, strap pressure, and difficulty breathing.

TABLE 5. NUMERATION OF PHYSICIAN AND SUBJECT DECISIONS TO TERMINATE THE SUSPENSION

TYPE OF DECISION	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (Percentage)		
Medical	11 (85)	9 (69)	3 (23)
Voluntary	2 (15)	4 (31)	10 (77)

One case of syncope (loss of consciousness) occurred in a subject suspended in a full-body harness. The syncope occurred while the subject was being lowered from the suspension. The subject had requested termination of the suspension because of symptoms of feeling flushed. The subject was unconscious for approximately 30 seconds, and recovered quickly without any medically adverse effects when placed in the supine position. The EKG revealed a significant bradycardia in which the heart rate decreased to approximately 30 beats per minute. The bradycardia persisted for approximately 20 seconds before the EKG returned to a normal sinus rhythm and rate.

In almost all instances the heart rate and respiratory rate increased while the subject was suspended in a harness (Table 6 & 7). The magnitude of the increase in heart rate and respiratory rate was variable among subjects and harness types. Graphs of the change in heart rate from baseline during particular intervals of the experiment for the chest harness and full-body harness are shown in Figures 15 and 16.

TABLE 6. NUMERATION OF THE CHANGE IN HEART RATE COMPARING BASELINE VALUES TO VALUES AT SUSPENSION TERMINATION

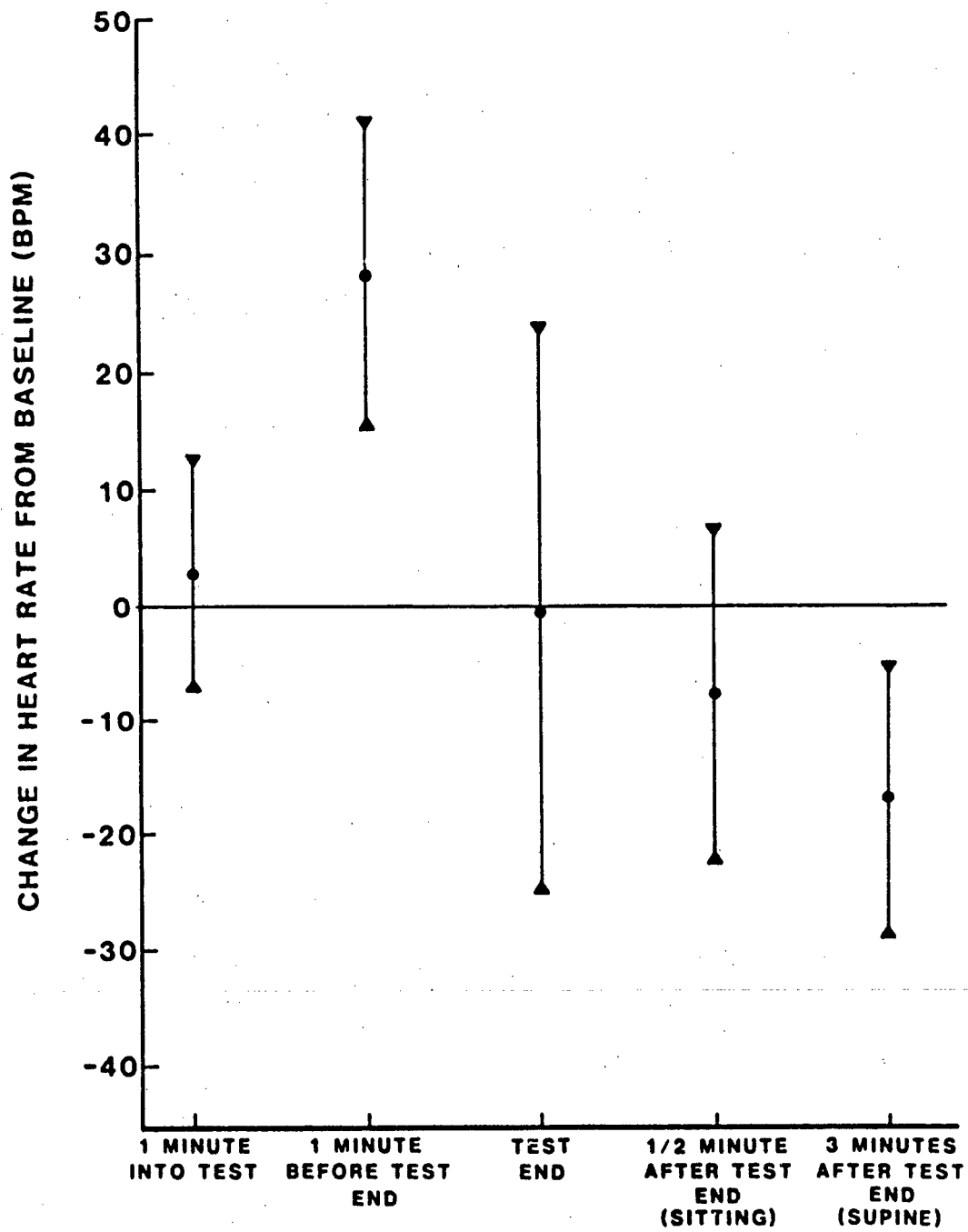|	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (Percentage)		
Heart Rate Increase	12 (92)	12 (92)	12 (92)
Heart Rate Decrease	0 (0)	0 (0)	0 (0)
No Change	-	-	1 (8)
No Data	1 (8)	1 (8)	-

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FIGURE 15. CHANGE IN HEART RATE FROM BASELINE - FULL-BODY HARNESS
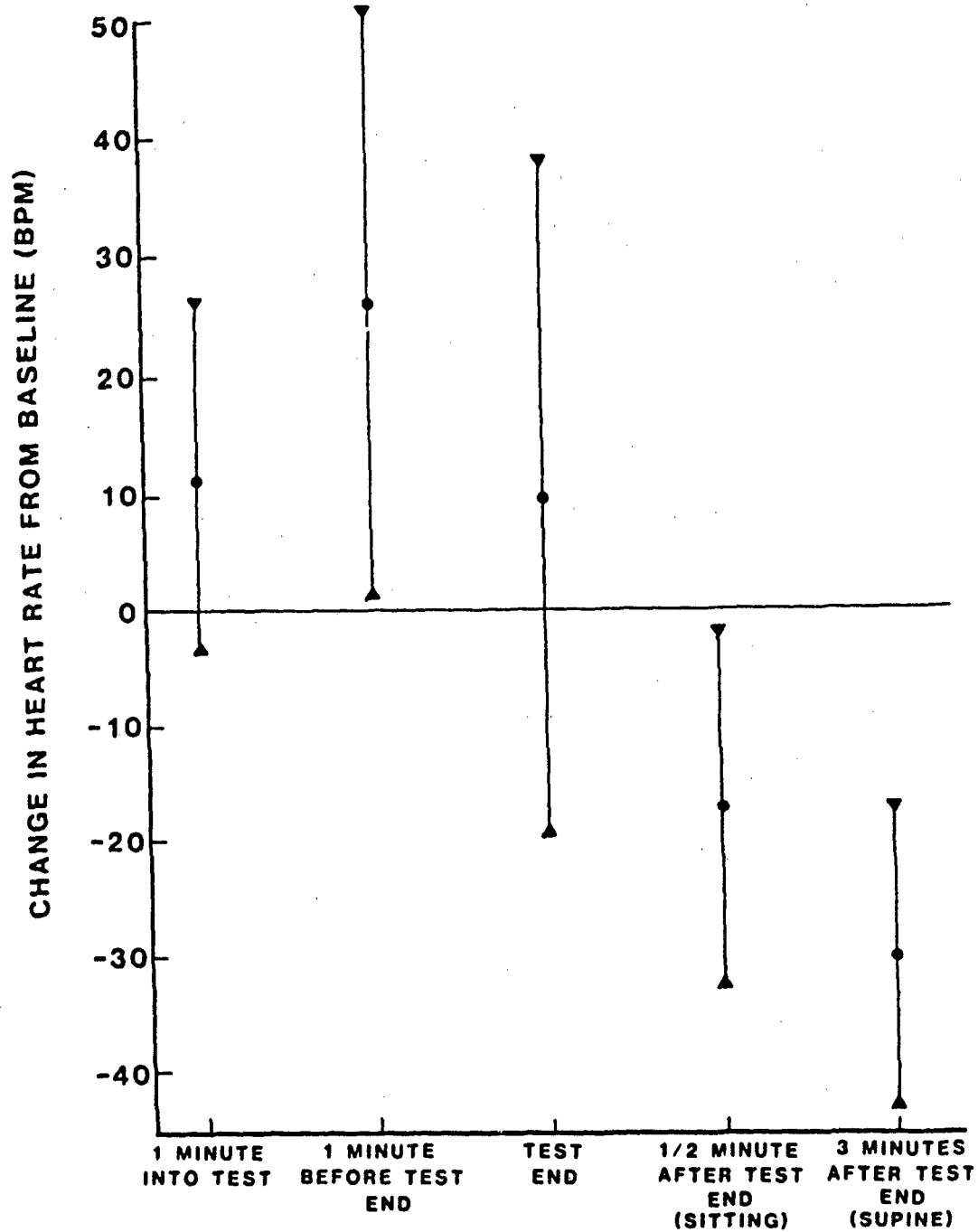
FIGURE 16.   CHANGE IN HEART RATE FROM BASELINE – CHEST HARNESS

TABLE 7. NUMERATION OF THE CHANGE IN RESPIRATORY RATE
COMPARING BASELINE VALUES TO VALUES AT SUSPENSION TERMINATION

	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (Percentage)		
Respiratory Rate Increase	10 (77)	10 (77)	9 (69)
Respiratory Rate Decrease	2 (15)	1 (8)	2 (15)
No Change	1 (8)	2 (15)	1 (8)
No Data	-	-	1 (8)

The frequency of the occurrence of symptoms of nausea, light-headedness, and difficulty breathing among the three harnesses is presented in Table 8. Nausea and light-headedness occurred more frequently with the chest harness and full-body harness than with the body belt. Difficulty breathing was a symptom experienced by all of the subjects with the body belt; this was due to the abdominal pressure caused by the body belt.

TABLE 8. NUMERATION OF OCCURRENCE OF LIGHT-HEADEDNESS, NAUSEA
AND DIFFICULTY BREATHING FOR THREE HARNESSES

	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
SYMPTOM CATEGORY	NUMBER OF REPORTS (Percentage)		
Light-headedness	7 (54)	9 (69)	2 (15)
Nausea	8 (62)	5 (38)	2 (15)
Difficulty Breathing	2 (15)	7 (54)	13 (100)

Table 9 presents the occurrence of numbness and tingling, which are forms of extremity paresthesias. Numbness and tingling of the upper extremity occurred more frequently with exposure to the chest harness. There was a predominance of lower extremity symptoms with the full-body harness.

Table 10 presents the location of the symptoms of the strap pressure for the three harnesses. The body belt produced significant pressure in the abdominal area. The chest harness produced pressure in the areas of the abdomen and axilla, while the full-body harness produced pressure in the groin and thigh areas.

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TABLE 9. NUMERATION OF OCCURRENCE OF NUMBNESS, TINGLING, AND LIMB
HEAVINESS IN THE UPPER AND LOWER EXTREMITIES

SYMPTOM CATEGORY	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (Percentage)		
Upper-Extremity Numbness	1 (8)	7 (54)	2 (15)
Lower-Extremity Numbness	9 (69)	2 (15)	1 (8)
Upper-Extremity Tingling	6 (46)	11 (85)	6 (46)
Lower-Extremity Tingling	12 (92)	4 (31)	3 (23)
Upper-Extremity Limb Heaviness	1 (8)	8 (62)	3 (23)
Lower-Extremity Limb Heaviness	8 (62)	2 (15)	2 (15)

TABLE 10. NUMERATION OF LOCATION OF SYMPTOMS OF STRAP PRESSURE

STRAP PRESSURE LOCATION	FULL-BODY HARNESS	CHEST HARNESS	BODY BELT
	NUMBER OF REPORTS (PERCENTAGE)		
Neck	2 (15)	3 (23)	0 (0)
Axilla	0 (0)	13 (100)	0 (0)
Chest/Rib	4 (31)	4 (31)	1 (8)
Abdomen	1 (8)	12 (92)	13 (100)
Groin	13 (100)	0 (0)	0 (0)

Cardiac dysrhythmias that were observed included tachycardia, bradycardia, and premature ventricular contractions.

SECTION 5
DISCUSSION

A. PHYSIOLOGICAL IMPLICATIONS OF FINDINGS

Hearon and Brinkley (1984) theorized that the clinical findings associated with prolonged motionless suspension may be due to venous pooling in the extremities as the result of failure of the skeletal muscle pump to return venous blood to the heart. The pathophysiologic consequences of peripheral venous pooling include a decrease in central venous pressure and venous return of blood to the heart. Other consequences include tachycardia, inadequate tissue perfusion, light-headedness, and loss of consciousness. These clinical findings have been observed in human suspension tests accomplished by other experimenters (Amphoux, 1982a, 1982b; Bauman, 1968; Nelson, 1979) as well as during the experiments reported herein.

Another mechanism which can cause some of the clinical findings associated with motionless suspension is the vasovagal (vasodepressor) response. During a vasovagal event, individuals may experience hypotension, bradycardia, and loss of consciousness in response to environmental stresses. The bradycardia is the result of vagal stimulation. In addition, other authors have suggested that profound vasodilation of skeletal muscle arterioles occurs which results in an accompanying drop in blood pressue (Goldstein et al, 1982). The prodromal symptoms of a vasovagal attack are pallor, nausea, sweating and abdominal discomfort arising from sympathoadrenal and vagal responses. Loss of consciousness occurs as a result of cerebral ischemia from hypotension.

The symptoms of light-headedness and syncope attributed to the presence of hypotension are a result of both or either of the above described mechanisms. When both of these mechanisms are present the effect is additive and can result in a precipitous drop in blood pressure.

Unfortunately, the physiological measurements that were taken during this experiment were inadequate to quantify the degree to which these mechanisms, individually or in combination, may have been responsible for the observed symptoms. Additional experiments with invasive measurements of blood pressure and cardiac output would be required to accomplish this task.

The existence of either the venous-pooling mechanism or the vasovagal-response mechanism have serious implications for individuals with cardiovascular disease. Such individuals may be at increased risk of injury during motionless suspension due to the stress on the cardiovascular system. In addition, those members of the population with respiratory disease may also be at increased risk of injury or less tolerant of suspension.

Heart rate and respiratory rate increased in almost all of the suspensions irrespective of harness type. The magnitude of the increase was variable.

The tachycardia noted during the tests is consistent with anxiety as well as the physiological response to decreased effective blood volume. The

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Tachypnea observed is consistent with anxiety as well as decreased vital capacity as a result of decreased chest wall motion from the restriction of a harness or decreased chest cavity volume from abdominal contents pushed upward from abdominal pressure applied by a harness.

The symptom of paresthesia of the extremities is a result of decreased blood flow to the extremities and/or direct pressure on the nerves supplying the extremities, or the effects of both. Since the subjects were instructed to remain motionless during the suspension, the skeletal muscle pump was not active to maintain circulation. For instance, in the chest harness, the subjects experienced pressure at the axilla, which led to upper-extremity numbness. In the full-body harness, pressure was concentrated in the groin and thigh areas causing tingling and numbness in the lower extremities. Other authors have also observed paresthesias of the extremities during harness suspension tests (Amphoux, 1982a, 1982b; Bauman, 1968; Damish, 1985; Nelson, 1979).

The concentrated pressure of the waist belt against the soft tissue of the abdomen was an important limitation to suspension duration in the body belt. In contrast, the full-body harness distributes the pressure over a larger area of the body. The full-body harness also distributes the pressure to the bony structures, which can tolerate greater pressure than soft tissue areas. The chest harness applied a large amount of pressure to the axillary region, and in contrast, the full-body harness was able to decrease this pressure by use of the thigh straps and buttock sling. The waist belt of the chest harness also applied pressure to the abdomen that forced abdominal contents upward, decreasing the volume of the chest cavity and contributing to the symptom of difficulty breathing.

B. OTHER CONCERNS

The potential for injury during fall arrestment is a safety issue that was not addressed in these experiments. However, some observations concerning the potential for injury in each of the harness tested can be inferred.

Although the body belt may be inexpensive, easier to don, and less encumbering, the body belt has many apparent disadvantages. First, internal injuries are more likely during a fall arrestment since the body belt applies the arrestment force to the soft tissue of the abdomen and its internal organs. Second, if the fall-arrestment lanyard is attached laterally or dorsally, the arrestment force may cause injury due to hyper-abduction or hyper-extension of the spine about the body belt. Third, there is a greater potential for an occupant to slip out of the waist belt during fall arrestment or during suspension. This potential may be increased where an individual's waist diameter exceeds his or her chest or hip diameter. Fourth, if the occupant is unconscious and motionless after a fall, the occupant may not be able to adjust his or her position to be more comfortable and to decrease the amount of abdominal pressure. Our subjects found that while they were suspended in a horizontal position in the body belt, they were not able to tolerate the increased abdominal pressure for very long. Furthermore, during preliminary suspension tests preceding our experiment, most of the subjects were unable to attain a body position that would provide relief from the abdominal pressure.

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The chest harness offers more upper-torso body support compared to the body belt. However, the apparent disadvantages of the chest harness are significant. First, occupant breathing is restricted during suspension by the straps that encircle the chest. Second, pressure from the weight of the individual during suspension or fall arrestment is concentrated at the axilla. This axillary pressure is less tolerated compared to the pressure concentrated in the groin area by the full-body harness. Third, chest injuries that may be incurred during fall arrestment can be life threatening, e.g., rib fractures complicated by a pneumothorax or myocardial contusion.

During the suspension tests, the full-body harness was found to be the superior harness because of its ability to distribute pressure over a larger proportion of the body and the bony structures. The full-body harness also appears to be the superior harness for protecting its occupant during abrupt deceleration from a fall. This observation is based upon the similarity of the full-body harness to parachute harnesses that are routinely used, without injury, by both military and sport parachutists.

The full-body harness, which was used in this test program, was chosen from several styles available from the manufacturer because its thigh-strap configuration indicated a possibility for increased pressure in the groin area that might shorten occupant suspension time. Other full-body harness styles available from this manufacturer as well as others, provide a strap in the area of the occupant's buttocks, which acts like a seat and thereby decreases pressure over the anterior groin area where the major blood vessels and nerves supplying the lower extremities are located. In the opinion of the investigators, the reduced pressure in the groin area decreases the potential for venous pooling in the lower extremeties and, thus, increases the suspension duration. This hypothesis, of course, must be evaluated by experimentation.

A paucity of experimental data is available on the effects of forces acting on individuals in parachute harnesses and fall protection harnesses during abrupt deceleration. The formulation of more accurate fall-arrestment force limits and parachute opening-shock limits cannot be accomplished without a better understanding of the biomechanical response of the human body. Measurement of fall-arrestment forces, parachute-riser forces, and harness force distribution is vital. Measurement of the deceleration forces carried by fall protection harnesses and parachute harnesses with volunteers is the next logical step in the evaluation of the capabilities and protection provided to the occupant during abrupt deceleration.

SECTION 6
CONCLUSIONS

The conclusions of this test program are summarized as follows:

1. The full-body harness that was evaluated had the longer mean suspension duration (14.38 min) compared to the chest harness (6.08 min) and the body belt (1.63 min).

2. Statistically significant differences in suspension durations were demonstrated by the Wilcoxon paired-replicate rank test.

3. The body belt was tolerated the least due to abdominal pressure and difficulty breathing.

4. The full-body harness had a predominance of lower-extremity symptoms since strap pressures were concentrated in the groin and thigh area.

5. The full-body harness provided improved body support by distributing pressure over the bony skeleton.

6. The chest harness had a predominance of upper-extremity symptoms due to pressure concentration at the axilla.

7. Heart rate and respiratory rate tended to increase with suspension duration.

8. Prolonged motionless suspension may result in cardiovascular responses including tachycardia, bradycardia, and bradycardia with subsequent loss of consciousness.

APPENDIX A

SUBJECT RESPONSE QUESTIONNAIRE - HUMAN RESPONSE TO PROLONGED SUSPENSION (HRPS)

"PLEASE ANSWER THE FOLLOWING QUESTIONS USING THESE RESPONSES:"

a. NO (0)
b. YES, A LITTLE (1)
c. YES, SOME (2)
d. YES, MUCH (3)
e. YES, VERY MUCH (4)

AFTER THIS INITIAL RESPONSE, PLEASE SPECIFY, QUANTIFY, AND ELABORATE UPON YOUR ANSWER.

1. Do you feel anxious?
2. Are you having difficulty breathing?
3. Are you experiencing any dizziness?
4. Are you experiencing any changes in vision?
5. Are you experiencing any changes in hearing?
6. Are you experiencing any feelings of nausea?
7. Are you experiencing any numbness in your legs?
8. Are you experiencing any tingling in your legs?
9. Are you experiencing any numbness in your arms?
10. Are you experiencing any tingling in your arms?
11. Are you experiencing any headache pain?
12. Do you feel flushed?
13. Do your limbs feel heavy or full?
14. Are you experiencing any sensations of bodily temperature changes?
    If so, where?

GENERAL CONDITION QUESTIONS

1. Where is the majority of the strap pressure?
2. Where is the most discomfort? How discomforting is it?
3. How do the straps feel?
4. Are you experiencing pain? Where is it located?
5. What was the primary reason for test termination?

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